SEISMIC SAFETY ELEMENT
OF THE ALAMEDA COUNTY GENERAL PLAN

Alameda County Planning Commission
July 31, 1975
Revised September 29, 1975
Adopted by the Alameda County
Board of Supervisors January 8, 1976

2- SEISMIC SAFETY ELEMENT

I. INTRODUCTION

A. Authority

Government Code Section 65302(f) requires a seismic safety element of all city and county general plans, as follows:

> A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.
>
> The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure and seismically induced waves.

The effect of this section is to require cities and counties to take seismic hazards into account in their planning programs. All seismic hazards need to be considered, even though only ground and water effects are given as specific examples. The basic objective is to reduce loss of life, injuries, damage to property, and economic and social dislocations resulting from future earthquakes.

B. Background

Earthquakes do not occur in all parts of the world due to the nature of the way they are created; some tectonic movement must be present to cause an earthquake. The Circum-Pacific seismic belt where over 80% of the world's earthquakes occur is shown in the illustration. In addition to the point that California and the Bay Area are clearly within this seismically active zone, the illustration shows the location of the potential origins of tsunamis, chiefly the gulf of Alaska.

The summary catalogue of earthquakes by Wood and Heck lists the following as "Great Shocks" in California:

1769, July 28	1857, January 9	1906, April 18
1790?	1868, October 21	1915, October 2
1812, December 21	1872, March 26	1922, January 31
1836, June 10	1873, November 22	1932, December 20
1838, June	1892, February 23	1940, May 18

> Those of 1812, 1838, 1857, 1872, and 1906 are further qualified as "outstanding." Other shocks marked "strong" number 20 for 1800-1903 and 16 for 1909-1950. (Those so marked to which magnitudes can be assigned with any confidence are of magnitude 6 or over.)[1]

In more recent years, strong earthquakes have caused great damage and loss of life (San Fernando, 1971, and Arvin-Tehachapi, 1952) and moderate damage (Oroville, 1975).

[1] Elementary Seismology, C. F. Richter, 1958, page 472

C. City-County Coordination

City-County coordination in the preparation of seismic elements has occurred primarily through the referral process between local jurisdictions. In the preparation of the Hayward Area Shoreline Policies, adopted in 1974, Alameda County, the cities of Hayward and San Leandro, East Bay Regional Park District and Hayward Area Recreation and Park District coordinated in the preparation of a shoreline geological study by a consultant. This referral process involves all city and county plans which relate to seismic policies and plans including general plans, open space, conservation, safety and seismic elements. In addition plans are being formulated for the systematic collection and storage of seismic data and information by the County with continuing input from the cities. Other city-county coordination is discussed in the seismic element implementation section.

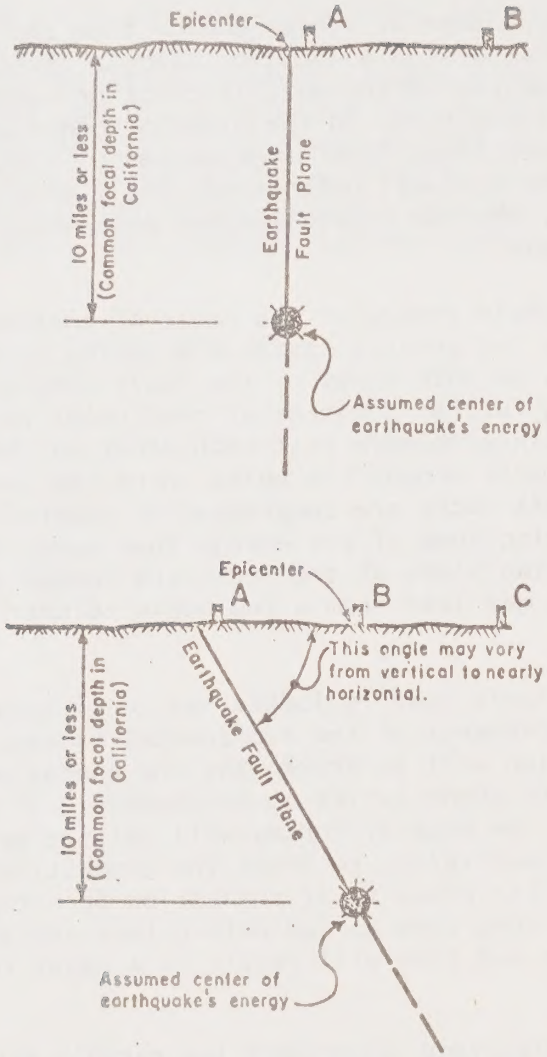
Earthquakes, Causes and Terminology

An earthquake is a release of stored energy from the earth's crust. The energy is released at a single location along a fault or plane of weakness between two large masses of the earth's crust or outer surface. The crust, is about 10 to 15 miles thick in the Alameda County area. The crust is fractured along fault lines into large masses of rock. At a global scale, for reasons that are not well understood, the pieces of the earth's crust are moving. Typically, the two crustal masses move past one another at a rate less than an inch per year.

The more generally held theory of the cause of earthquakes is the elastic rebound theory. As two crustal masses are moving by one another, strong and protruding sections on both sides of the fault become locked together by friction preventing further movement at that point on the fault. The two crustal masses continue to move past each other and begin to build up stress and strain in the rocks around the point where the two crustal masses have become joined. These rocks are compressed or sheared and stretched like giant springs, storing some of the energy that moves the crustal masses. This phase in which the two sides of the fault are locked together and stress builds in the rocks may last from a few weeks to over one hundred years or longer.

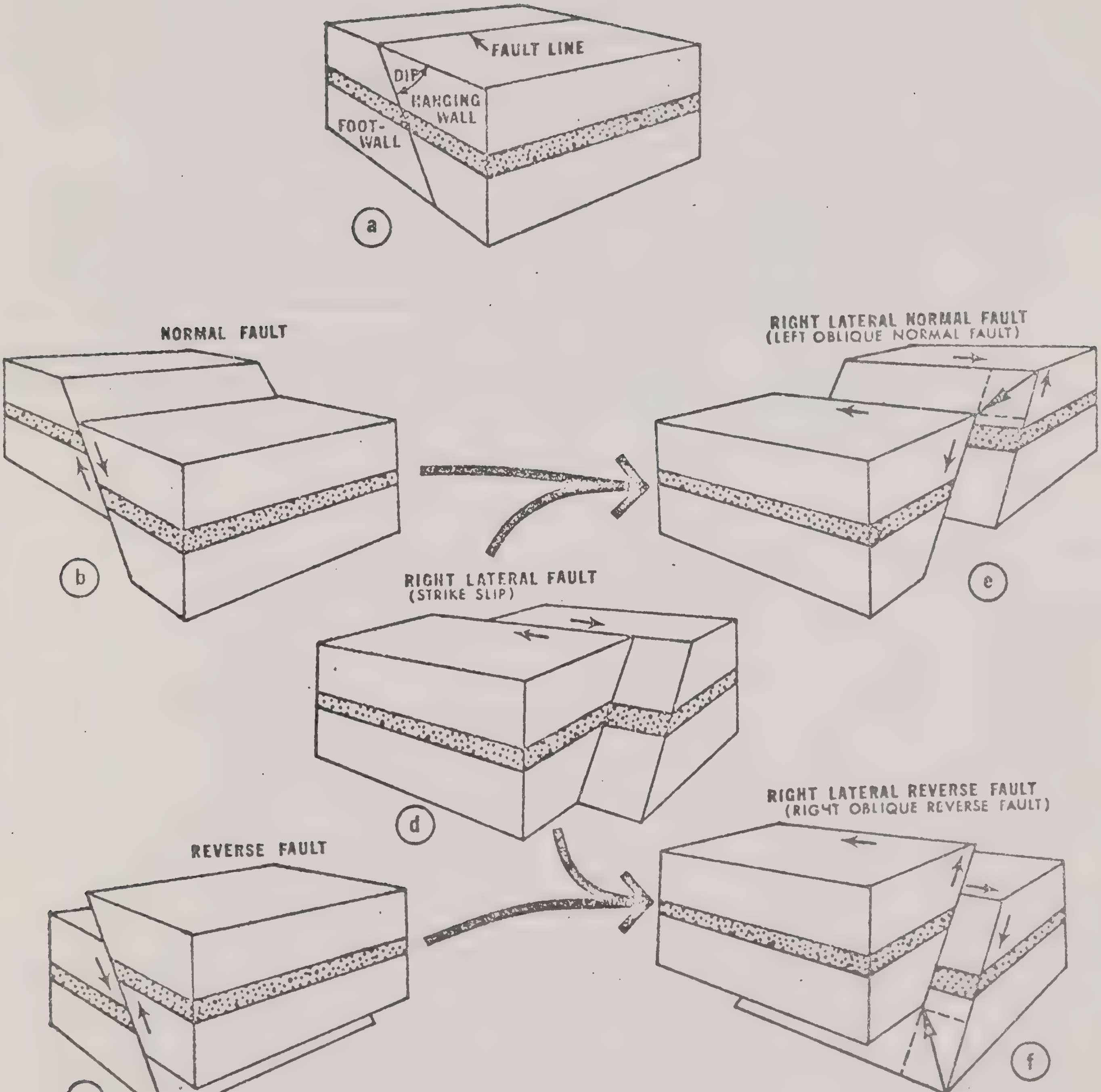
The section of the fault that is locked has to withstand the forces applied by the continuing movements of the two crustal masses. Inevitably, the cross-fault connection will be broken and the energy stored in the rocks released; this is the event called an earthquake. If the cross-fault connection is weak, the crustal forces will only be accumulated for a short time until they are sufficient to break the connection and cause a mild earthquake. Should the cross-fault connection be strong, the crustal forces may build up over a long time period before they are strong enough to break the connection and this will result in a major release of energy, a major earthquake.

The line where a fault plane intersects the earth's surface is called a fault trace. The point on the fault where maximum energy is released is called the earthquake focus. The depth of the focus below the earth's surface is normally 10 miles or less with the average depth being closer to 5 miles in California. The point on the ground surface directly above the earthquake focus is called the epicenter. The epicenter will seldom coincide with the trace of the causative fault because the planes of most faults are not perpendicular to the earth's surface. Instead, most fault planes tilt or dip to one side of the surface fault trace.



Two idealized earthquake faults. See text for discussion of relationships between surface intensity and trace of the fault.

Source: <u>Earthquake Hazards in the San Francisco Bay Area</u>, Steinbrugge



All of the above examples of faulting have occurred in and around the City of Hayward.

Source: Hayward Earthquake Study, April 1972

The energy release of an earthquake results in some movement of the two crustal masses with respect to each other; sometimes the movement is apparent at the ground surface. The movement is abrupt and irregular. The relative movement or faulting has been sub-divided by type of movement. The horizontal movements tend to be much greater than the vertical movements in California. There is no general pattern to the vertical movements, but the horizontal shift is repeated in the same way each time; when standing on one side of the fault, the other side will usually move to the right. This situation applies to most of the major faults in California and is called right-lateral movement.

The energy released in an earthquake ranges from an amount so small that it goes unnoticed except by the most sensitive instruments to an amount so large that it can destroy any man-made structure within its range. The numerical units of energy released in a strong earthquake are astronomical. A scale was invented in 1935 by Charles F. Richter to measure earthquake energy. The Richter Scale measures the magnitude of an earthquake on a logarithmic scale from zero to ten using instruments. As a result of using the logarithmic scale, earthquakes of higher magnitude represent vastly greater energy release than earthquakes of lower magnitude.

II. SEISMIC HAZARDS

The San francisco Bay Region including Alameda County is recognized as one of the areas in California in which there is currently a high frequency of earthquakes (Oakeshott, 1969). The bay counties have experienced about 12 damaging earthquakes in the past century and based upon studies of repeated geodetic measurements across the major fault zones, seismicity and calculated rates of strain accumulation, it seems reasonable to expect a great earthquake (comparable to the San Francisco earthquake of 1906) once in 60 to 100 years (Oakeshott, 1969). The history of great earthquakes in the world indicates that there is no regular periodicity, so it is obvious that such figures cannot be used for earthquake prediction but only for expected frequency. However, all evidence points to the conclusion that areas of historically high seismicity are the places where damaging earthquakes are likely to center in the future.

A summary of locations of major earthquakes in the Bay Area is shown in figure 2-2, adapted from a geotechnical study by Burkland and Associates (1975). The historical record contains five entries generally accepted to be the largest known shocks in the Bay Area. These are as follows (Steinbrugge, 1968)[1]:

1. June 10, 1836, on the Hayward fault. At 7:30 a.m., cracks and fissures opened up along this fault from San Pablo to Mission San Jose.
2. June, 1838, probably on the San Andreas fault. A fissure was described as extending from near San Francisco to near Santa Clara.
3. October 8, 1865, probably on the San Andreas fault. Considerable damage occurred in San Francisco. The earthquake presumably had its epicenter on the San Andreas fault in the Santa Cruz Mountains.
4. October 21, 1868, on the Hayward fault. At 7:52 a.m. cracks and fissures from this earthquake formed from about San Leandro to about Warm Springs. Very heavy damage occurred in the town of Hayward, and there was also extensive damage in sections of San Francisco.
5. April 18, 1906, on the San Andreas fault. At 5:13 a.m., the well known San Francisco shock occurred. Faulting extended from southern Humboldt County to near San Juan Bautista in San Benito County.

   Although all of these earthquakes were undoubtedly of different Richter magnitudes, they all appear to have been of sufficient size to approach or equal the maximum probable future earthquake intensities to be expected in at least major sections of the San Francisco Bay Area. Instrumental data do not exist for the pre-1906 shocks, and even the historical data are meager for the 1836 and 1838 shocks.

The more significant earthquakes that have occurred in the Bay Area during the period 1950 to present are listed in Table 1.

[1]Source: Earthquake Hazards in the San Francisco Bay Area, Steinbrugge

Note: Sections II, III and portions of Section VI were prepared by David Carpenter, County Engineerinmg Geologist

Table 1[1]

Recent Bay Area Earthquakes

Date	Location	Richter Magnitude
April 25, 1954	Watsonville	5.3
September 4, 1955	San Jose	5.8
October 34, 1955	Walnut Creek	5.4
March 22, 1957	San Francisco (Daly City)	5.3
September 14, 1963	Chittenden	5.4
October 1, 1969	Santa Rosa	5.7
November 28, 1974	Hollister	5.25

None of these earthquakes were of major proportions although locally significant damage occurred in Santa Rosa during the October 1, 1969, event; and ground-shaking was sufficiently violent to cause the collapse of open utility trenches as far away as Pleasanton (Burkland & Associates, 1975).

Since the San Francisco Bay Area, including Alameda County, is recognized as an area of active faults and high earthquake frequency considerations of public safety and responsible future development require an evaluation of events that may reasonably occur during a moderate to great earthquake.

Oakeshott (1969) determined that the results of critical field examination of the characteristics of hundreds of faults and particularly of the geologic features accompanying dozens of earthquakes in western North America demonstrated that damage resulting from earthquakes is dependent upon several specific geologic phenomenon. The following descriptions of earthquake effects is excerpted from the above cited summary.

Ground Shaking

Ground-shaking--the earthquake itself--consists of complex surface wave motion which has traveled through the rock materials of the outer crust. Earthquake waves, like other waves, may be reflected refracted attenuated, and change velocity and period as they pass through different materials, thus making the ground motion complex. In general, earthquake waves, in passing from more dense solid rock to less dense alluvial and water-saturated materials, tend to become reduced in velocity, increased in amplitude, and accelerations become greater. Ground motion lasts longer on loose water-saturated, incompetent materials than on rock, it is also amplified to an unknown extent. Due to a combination of factors, structures located on such materials suffer far greater damage than those located on solid rock. This has been repeatedly and strikingly demonstrated in large earthquakes, including Toyoko 1923, Fukui 1948, Arvin-Tehachapi 1952, Chile 1960 and Alaska 1964. In all these cases, and many others, the violence of ground motion in soft alluvial materials was significantly grater than in solid rock. Amplification of ground motion is greatest in unconsolidated saturated sediments.

To bring the experience closer to home, the Earthquake Commission Report on the San Francisco 1906 earthquake documented exaggerated shaking in the lower waterfront areas of San Francisco, underlain by the thickest bay mud and fill, as compared to lesser shaking in Nob Hill and similar areas with more solid rock at or near the surface. Many earthquakes have shown that "poor ground" is a greater

hazard than proximity to the fault and epicenter. In 1906, Santa Rosa and San Jose, both underlain by alluvium, suffered to an extent out of proportion to their distances from the fault movement. There is some evidence to show that ground motion tends to increase with the depth of alluvium.

Unfortunately, comparatively little instrumental data exists on the difference in response of different types of rock and soil to wave motion. One of the greatest research needs is to establish a close network of strong-motion seismic instruments on the different kinds of rock and soil in many spots in and around the bay to monitor and record the effects of the dozens of minor —and the occasional major—earthquakes felt in this area every year. This would yield extremely valuable data fundamental to development of the bay and its margins.

Surface Faulting

Fault rupture, which begins at the focus, may extend to the surface, especially in moderate to large earthquakes. The direction of separation of the earth on opposite sides of a fault plane may be vertical, horizontal, or oblique. In moderately large earthquakes, surface scarps (the exposed scar) may well be as high as 20 feet (Hebgen Lake, Montana, 1959, magnitude 7.1) or, in smaller earthquakes, only a few inches high (Herlong, Plumas County, California, 1950, magnitude 5.75). Recently observed movements on the San Andreas, Hayward, and Calaveras faults seem to be of the horizontal type, east block moving relatively south. Maximum displacement of this type, San Francisco 1906, magnitude 8.25, was 20 feet, just south of Tomales Bay; Hayward 1868 was 3 feet; Fort Tejon, 1857, was perhaps as great as 30 feet. Arvin-Tehachapi 1952, magnitude 7.7, on the White Wolf fault, had oblique-slip displacement amounting to about 2 feet of upward movement on the south and a like amount of horizontal movement, south block moving eastward. There was no surface faulting in the San Francisco 1957, magnitude 5.3, earthquake. While historical displacements on the faults of the San Andreas system have been predominantly horizontal, there is much geological evidence to show that slightly older movements have involved a great deal of vertical displacement. Vertical movement on faults in future earthquakes in the bay area cannot be ruled out. Judging from geology and earthquake history, it appears unlikely that important active faults exist in rock under the bay itself, except that the Hayward fault probably extends to the north across San Pablo Bay. Surface faulting not only develops scarps, but also trenches (graben), patterns of ground fractures, "mole tracks" or pressure ridges, and open or closed fissures.

Recently, evidence has been accumulating that spasmodic slippage ("creep") is now occurring on the Hayward fault trace and on the San Andreas fault, with many individual slips not accompanied by felt earthquakes.

Faulting not only disturbs the ground surface but also disturbs and dislocates drainage features, both natural and artificial. Springs and ground-water flow characteristics may be changed.

Landsliding

Landslides, rock falls, avalanches, mud and debris flows and general gravitational movements of loose and weathered rock and soil are major effects of ground shaking in earthquakes of magnitude 5 and greater. Such mass movements are readily triggered by earthquakes, especially where slopes are oversteepened from whatever cause, and where earth materials are water-saturated, from artificial means or the natural rainy-season. An immense amount of sliding takes place in large earthquakes but even small earthquakes, such as San Francisco 1957, cause many damaging slides. At Hebgen Lake, Montana 1959, a rock slide carried 43,000,000 cubic yards of loose rock across the Madison River. State Highway 1, on the coast south of San Francisco, was closed by large landslides in the small earthquake of 1957. The San Andreas, Hayward, and Calaveras fault zones are marked by a succession of many geologically-recent slides, many of them highly unstable. The steep hills on both sides of the bay are particularly vulnerable to sliding.

Recent work has shown that certain types of sandy and clayey sediments become "quick" as a result of shaking and lose all cohesive strength. Such materials may flow like a thick fluid down extremely low-angle slopes. Flow tends to be toward a "free" face, even though the flow may be nearly horizontal. Liquefaction was a major factor in the disastrous slides in the Turnagain Heights area of Anchorage in the Alaskan earthquake of March 27, 1964.

Lurch Cracking

The development of all types and sizes of irregular fractures, cracks, and fissures—largely as the result of sliding, settling and shaking, and the passage of surface earthquake waves—is characteristic, to a greater or lesser extent, in all earthquakes large enough for significant ground motion to occur. Such fractures may be many feet long and may displace surface weathered rock and soil both horizontally and vertically, just as true fault movement would. Lurch cracks rarely occur in solid rock; they are essentially confined to weathered rock, alluvium, and soil. Their patterns may be completely irregular or may show marked regularity where controlled by shallow bedrock, by the outline of natural or artificial fill, by highway surfacing, etc. Lurch cracking is often accompanied by sand boils and mud volcanoes as groundwater moves to the surface. Extensive and damaging lurch cracking has occurred in incompetent water-saturated materials in all moderate to large earthquakes (magnitudes 6 to 8). Damage resulting from this type of ground fracture was extensive in the waterfront areas of San Francisco in 1906, in the irrigated alluvium and soil of the southern San Joaquin Valley in the Arvin-Tehachapi earthquake of 1952, in the Long Beach earthquake of 1933,

and in similar materials in every earthquake of damaging intensity. Undoubtedly, such cracking will be a major damage factor in many areas of bay mud and fill in future earthquakes of moderate to large magnitude in, or near, the bay. Lurch cracking may occur in water-saturated sediments, soils, and alluvium at distances up to 75 miles from the epicenter, as demonstrated most recently in the Alaskan earthquake. There is some evidence to indicate that lurch cracking is perhaps most extensive in the deeper alluvial materials.

Subsidence, Slumping, Compaction, Uplift

Especially in great earthquakes, such as San Francisco 1906 and Alaska 1964, but also in moderately large earthquakes, such as Hebgen Lake 1959 and Arvin-Tehachapi 1952, there are extensive changes in level and elevation of the land surface. These may take the form of broad uplift or subsidence, tilting of limited to large areas, and local slumping on the order of massive landsliding. Such earth movements may even pass unnoticed in inland areas, but become major factors along the shores of seas, bays, and lakes. Since historic displacements on the faults of the San Andreas system have been largely *horizontal*, this category of ground movements has not so far been of overriding local concern. However, even small upward, downward, or tilting movements become of great concern along a highly developed shoreline, such as that of the bay.

Compaction of soils and alluvial materials may take place extensively, and irregularly, in soils and fine-grained water-saturated sediments. In an earthquake, this takes place primarily as a result of shaking; compaction is induced by the vibration. It may amount to a few inches or several feet in soft materials; it does not occur in firm rock.

Seismic Sea Waves (Tsunamis) and Seiches

The seismic sea wave, tsunami, or "tidal wave" is probably caused by faulting and other abrupt ground movements on the ocean floor in connection with a major earthquake. Such waves move at high velocity, as much as 300 to 400 miles per hour in the open sea, may have a wave-length of many miles, and have low relative amplitudes. At sea, they are not noticeable but pile up water on shore to heights of up to perhaps [illegible] feet. Search of the historic records shows that no tsunami has raised sea level along the California coast more than a few feet. This coast, nevertheless, has been visited by such waves several times, generated by distant earthquakes. Crescent City, California, was damaged and several lives were lost by this type of wave (which arrived close to the time forecast in warnings issued by the U.S. Coast and Geodetic Survey) caused by the Alaskan earthquake of 1964; the California coast was also affected by a tsunami in connection with Chilean earthquake of 1960. A rise of water of even 2 or 3 feet in San Francisco Bay due to a tsunami, if coupled with a high tide and on-shore wind, could do serious damage to near-sea-level developments. The tsunami warning system of the U. S. Coast and Geodetic Survey is efficient and should give [illegible] warning in ample time to reduce loss of life to almost zero. Unfortunately, experience has shown that people do not always heed such warnings.

A seiche is a periodic oscillation, or "sloshing" of water in an enclosed basin such as that of a lake or bay. It is usually due to earthquake motion, in connection with a moderate to large shock. The periods of oscillation range from minutes to hours, depending on the size and configuration of the basin affected. In great earthquakes, seiches have been observed several thousands miles from the epicenter. Seiches could only be damaging in San Francisco Bay in the event of a large earthquake and "right" combination of tide and wind.

Figure 2-1

Each symbol on this map represents the epicenter of one or more earthquakes at a specific location. In the case of multiple earthquakes in highly active areas only one symbol is plotted. Consequently, 2,172 symbols are plotted, representing a total of 5,695 epicenters.

Active and potentially active faults
Selected earthquakes, magnitude greater than 6.0, that occurred prior to 1934 have been included with notations, earthquakes less than magnitude 4.0 are omitted. Data slightly modified, mainly from California Division of Mines and Geology Seismic Safety Information (1972): Provisional fault map of California; and Preliminary earthquake epicenter map of California, 1934-1971 (June 30).

Source: Modified from Geologic and Seismic Hazards Investigation for Tract 3606, Pleasanton, California, March 1975, Applied Soil Mechanics, Inc.

FIGURE 2-2

III. EVALUATION OF SEISMIC HAZARDS IN ALAMEDA COUNTY

Alameda County is recognized as an area of high seismic risk. Two major active fault systems, the Hayward and the Calaveras, traverse the area and movement along these faults has resulted in damage during historic times. When historic seismicity is superimposed upon present development levels, the potential for a major disaster is evident.

Recent studies by the California Department of Water Resources (1966) and of the Lawrence-Livermore Radiation Laboratory (Wright 1974, Blume and Assoc., 1972) have developed evidence of possible activity along several other faults in the Livermore Valley and in the Altamont Pass area. The historic seismicity and degree of hazard presented by these faults is uncertain.

Generalized geologic conditions in Alameda County, descriptions of active and potentially active faults and a summary of knowledge concerning areas potentially subject to primary and secondary seismic hazards is contained in the following sections.

Generalized Geology of Alameda County:[1]

The general geologic setting of Alameda County is shown on the Generalized Geologic Map and the Map of Late Cenozoic Deposits. Active and potentially active fault traces are shown on a map in Section II.

a) Geology of the Western Portion of Alameda County

The part of Alameda County which lies west of the active Calaveras Fault includes the East Bay Hills from Albany on the north to the Mission District east of Fremont. Also included in this area is the Bay Plain from the base of the foothills to the edge of the San Francisco Bay. The rocks in the hills are older and considerably more complex than the relatively recent alluvial deposits of the Bay Plain. The complexity of the rocks in the hills is a function of their history of deformation and diversity of type and characteristics. For example, in the Berkeley-Albany hills, the following formations have been identified: Mesozoic ultrabasic intrusive rocks, Franciscan, Eocene marine, Plicene volcanic, middle and/or lower Pliocene nonmarine, and Pleistocene nonmarine. As one progresses south in the hills from Oakland to Fremont, the predominant formation becomes a sequence of upper Cretaceous marine sandstones and shales with strips of ultrabasic intrusive and metasedimentary rocks (Mesozoic), Pliocene volcanic, and middle and/or lower Pliocene nonmarine sediments occur along the western base of the hills. The East Bay hills are separated from the Bay Plain to the west by the active Hayward Fault system.

[1] Adapted from David M. Hill, Geologist, Calif. St. Department of Water Resources for Evaluation of Environmental Constraints for Solid Waste Management

The plain west of the foothills in Alameda County is comprised of Quatenary Alluvial deposits which have washed down from the hills and settled on top of the older rock formations. One may visualize the process of formation of this plain as a progressive accumulation of layers of materials of varying composition and permeability. Some of the layers which have been identified in the Quaternary alluvial deposits have come directly from the hills and some are a result of sedimentation of clays and muds while the area was partially or wholly submerged. This layering has occurred in such a fashion around the creeks pouring into the bay that humps, or cones, have formed at San Leandro, San Lorenzo, and Alameda Creek. These cones which are presently sources of ground water for residential and agricultural uses are called the San Leandro, San Lorenzo, and Niles Cones, respectively.

The alluvial deposits underlying the Bay Plain have been subdivided into several units by the U.S. Geological Survey (Helley and others, 1972) based upon variations in gross lithology and degree of induration. Interactions between alluvial types and groundwater levels are critical with respect to potentials for certain secondary seismic hazards as discussed in a following section.

Along the very western edge of the Bay Plain, the geologic formations do not alter appreciably from those mentioned in the previous paragraphs but the combined importance of the geologic, biologic, and man-interference with the bay and tidelands has resulted in both an interesting and sensitive environmental area. The historic marshes are undergoing a change to the characteristic plain, which is observed further inland. Indian shell mounds which were once located on the shores of the bay several centuries ago are now several miles from the shore. The bayshore areas are underlain chiefly by Younger Bay Mud, a predominantly soft gray silty clay (Goldman, 1969). The Younger Bay Mud locally contains lenses of fine, water saturated sand.

b) Geology of Livermore-Amador Planning Unit

The LAPU is located in the northwest-trending coastal range and is predominantly east of the active Calaveras Fault system. There are several unique features about the area. The upland sites which surround the Livermore Valley are composed of geologically older consolidated nonwater-bearing rock formations. This material also forms the foundation of the Livermore Valley at considerable depths. In the uplands area south of Livermore, the Franciscan Formation may be observed. With few exceptions, this is the oldest formation, and constitutes a major portion of the uplands. The Franciscan Formation is described as "graywacke, locally abundant red and green thin-bedded chert, siltstone and silty shale, minor conglomerate, limestone, bluegrey glaucophane-bearing schist and related metamorphic rocks. The Franciscan Formation in the Diablo Range is generally considered to be of Jurassic and possibly pre-Jurassic age."[1]

[1]"Stratigraphic Nomenclature-San Jose Sheet" in Explanatory Data San Jose Sheet, Geologic Map of Calif. Calif. State Department of Conservation, Division of Mines and Geology, Olaf P. Jenkins Edition, 2nd Printing, 1972 Cedar Mountain and along the portions of Cedar Ridge, Main Ridge and Apperson Ridge.

In the upland areas around Patterson Pass and the Carnegie Fault, a division occurs between the Franciscan and Del Valle Formations. This area stretches between Corral Hollow and Interstate 580 and is a jumbled mixture of upper Cretaceous marine, upper Miocene marine, and middle and/or lower Pliocene non-marine sedimentary rocks. Recent geologic studies suggest that some of the fault systems in this complex area are potentially active (Wright, 1974).

The region north of I-580 is underlain primarily by upper Cretaceous marine sedimentary rocks similar to those exposed in the East Bay Hills south of Castro Valley to Niles Canyon.

Again in the uplands areas between Niles Canyon and Monument Peak, the Cretaceous and Miocene marine and middle and lower Pliocene non-marine formation units are found interspersed with each other.

The upland formations primarily consist of marine sedimentary and meta sedimentary rocks. Only small amounts of igneous rock are apparent. Examples of Mesozioc ultra basic intrusive rocks may be observed in the uplands near the southern end of Del Valle Reservoir and east of Calaveras Reservoir.

The Livermore Valley was formed by an east to west downfold along the Calaveras Fault. The alluvial terraces and plains, recognizable at the mid-level elevations or rolling foothills north and south of Livermore constitute the second broad physiographic division of the LAPU area. This transition zone is divided into two areas based upon geologic units.

The foothills north of Livermore on the south slopes of Mt. Diablo, and in the prominent foothills along Doolan, Collier, and Tassajara Creeks north of Livermore and Arroyo Las Positas are underlain by middle and/or lower Pliocene non-marine sedimentary rocks identified as the Orinda and Neroly Formations.

The Orinda Formation has been subdivided into the Tassajara and Green Valley formations and is characterized by "red, gray, or brown, loosely consolidated sandstone and conglomerate, subordinate amounts of shale, claystone, limestone lenses, and tuffaceous bentonitic clay."[1] The Tassajara Formation, more appropriately associated with this area, consists of "brown to gray mudstone, andesitic sandstone, conglomerate, and minor bentonitic and pumiceous tuff."[1] The Orinda is basically a continental flood plain deposit with discontinuous marine beds at the base.[2]

South of Livermore and Pleasanton the low foothills consist of Plio-Pleistocene non-marine sedimentary deposits of the Livermore gravel formation. The Livermore gravel is characterized by "loosely consolidated

[1] "Stratigraphic Nomenclature - San Jose Sheet" in Explanatory Data San Jose Sheet, Geologic Map of Calif. Calif. State Department of Conservation, Division of Mines and Geology, Olaf P. Jenkins Edition, 2nd Pringing, 1972 Cedar Mountain, and along the portions of Cedar Ridge, Main Ridge, and Apperson Ridge.
[2] Geologic Guide book of the San Francisco Bay Counties Bulletin 154, Calif. Division the Ibid foothills south of Livermore and Pleasanton, of Mines and Geology, 1951 (p. 143).

sand, gravel, clay, and local tuff beds (contains Pliocene fresh water invertebrate fauna and Pleistocene vertebrate fauna.)"(State of California, 1972.)

The low lands of the Livermore Valley consist of recent alluvial deposits surrounding minor areas underlain by the Orinda and Livermore formations. Surficial portions of the alluvial sequence have been subdivided by the U.S. Geological Survey into several units based on gross lithologic characteristics and degree of induration (Helley and others, 1972). Studies by the California Department of Water Resources (1974) have revealed similar horizontal and vertical variations in the subsurface. Goundwater contained in the recent alluvial deposits and in the Livermore Formation represent a significant resource and minor amounts of ground water have been produced from the Tassajara formation.

Within the LAPU, at least 17 faults have been identified. Some show possible evidence of geologically recent movement. Some form groundwater barriers in Pleistocene materials and others appear to be old faults that affect only Pliocene or older bedrock materials.

As mentioned above, the Livermore Valley has developed in an east-west dipping downfold or syncline terminating against the Calaveras Fault and the uplifted Pleasanton Ridge block. At the base of the Altamont Hills is the Greenville Fault which terminates near Arroyo Las Positas. In the southern section of the Altamont Foothills, the Patterson Pass, Tesla, Carnegie, and Corral Hollow Faults are found. The faults run parallelto each other between the Livermore and San Joaquin Valleys. East of Altamont Pass near Grant Line Road is the Midway Fault which is located in a local depression along Grant Line Road.

The faults found in the upland hills between Tesla Creek and the Mission Hills (Monument Peak) are the Valle, Williams, Verone, Indian Creek, McGuire Peaks, Welch and Calaveras. Among these, the Calaveras and Verone-Williams-Valle Systems appear to be the most prominent.

Within the lowlands of the Livermore Valley, several faults have been identified; they are the Livermore Fault and its branch, the Parks Fault, the Pleasanton Fault and its branches, and the northern section of the Calaveras Fault. In the vicinity of Dublin, the Gravel Pit and the Dublin Faults are observed in the foothills.

Active Fault Systems

Historic fault movements have been clearly established for two fault systems within Alameda County. These are the Hayward Fault which passes thorugh the urbanized western portion of the County along the boundary between the Bay Plain and the East Bay Hills and the Calaveras Fault system which passes through suburban and rural areas in Sunol, Livermore and San Ramon Valleys.

a) Hayward Fault: Two of the five recorded major earthquakes in the Bay Area have been correlated with the Hayward Fault (Steinbrugge, 1968) within Alameda County. In recent years, damage to structures ranging from Berkeley to Fremont as a result of tectonic creep along the fault has been confirmed (U. S. Geological Survey, 1966). Creep monitoring studies by the U.S.

Geologic Survey shown an average of 6 millimeters per year of right lateral movement (Burford, 1975).

Ground rupture accompanied the 1836 and 1868 earthquakes (Steinbrugge, 1968) and geotechnical studies by private consulting firms (copies on file in the Alameda County Building Inspection Department) have documented offsets of recent soil layers along traces of the Hayward Fault.

Detailed evaluation of the Hayward Fault system (Woodward-Clyde and Associates, 1970) indicates that the maximum credible earthquake expectable would have a Richter magnitude of 7.5 and be accompanied by up to 7 feet of horizontal and 1½ feet of vertical offset. The maximum historic earthquake (1868 event) was estimated to have had a Richter magnitude of 6 3/4 and was accompanied by 3 feet of horizontal and one foot vertical displacement.

b) Calaveras Fault: Evidence for active seismicity along the Calaveras Fault within Alameda County is provided by a zone of historic ground breakage and by offset of soil layers along a known trace of the fault system in the Dublin area (Burkland and Associates, 1973, 1974) and near Castlewood Country Club (Judd Hull and Associates, 1975). The zone of ground breakage, locally visible as a scarp up to about 2 feet in height, has been correlated with an earthquake that occurred July 3, 1861, estimated Richter magnitude 6.6 (Burkland and Associates, 1975).

Evidence for tectonic creep on the Calaveras fault has been reported in the Sunol Area (Nason, 1975) and in the Dublin-Camp Parks Area (Gibson and Wollenberg, 1968). Distortions that could be related to fault creep are visible along a second trace of the fault within the Briarhills subdivision west of the Dublin District.

The maximum credible earthquake anticipated for the Calaveras Fault system is 7.5 (Greensfelder, 1974). No estimates are currently available as to the amount of horizontal and vertical ground displacements that could accompany such an event.

Potentially Active Faults

Evidence for recent activity has been cited by various sources for 11 other faults which are located entirely or in part of Alameda County. The evidence for activity along these structures is generally ambiguous and no clear correlation is evident between a major earthquake and any of these faults.

a) Pleasanton Fault: The Pleasanton Fault has been classified as active by the U.S. Geological Survey (Brown, 1970) and by the State of California (Slosson, 1974). Evidence for activity of the Pleasanton Fault consists of a tentative correlation of a swarm of small earhtquakes near Danville, Contra Costa County with the Pleasanton Fault (Brown and Lee, 1971) and reported evidence of creep in the Dougherty Hills north of Camp Parks (Slasson, 1974).

Faulting in the Orinda Formation was exposed in an exploratory trench excavated across the trace of the Pleasanton Fault adjacent to Old Ranch

Road, immediately north of the Alameda County line (Messinger, 1975). The pavement of Old Ranch Road is cracked and offset along this feature.

Studies by the California Department of Water Resources (1966) indicate that a groundwater barrier exists along the trace of the Pleasanton Fault beneath the Livermore Valley and that recent clayey alluvial deposits are thicker east of the fault trace than to the west. However, the upper aquifer (depth 80± feet) shows no evidence of offset. Seismic evidence presented by Wire (1972) suggested an offset in alluvial deposits 20 to 40 feet below ground surface.

Neither of these studies developed evidence for offset of near-surface soils and the credibility of recent activity on the Pleasanton Fault has been challenged (Burkland and Associates, 1975). They recently obtained a radiocarbon date of 5100±200 years for a sample taken at a depth of about 18 feet below ground surface in an undisturbed alluvial sequence exposed in the Arroyo Mocho canal north of Pleasanton. The undisturbed sequence overlies all presumed completed geologic study of the East County Government Center "Hill Site" south of Pleasanton found no evidence for faulting in the vicinity of the southerly extending trace shown on the California Department of Water Resources Map.

A review of evidence concerning activity on the Pleasanton Fault suggests the following:

1) The Pleasanton Fault exists as a distinct feature in Pleistocene and older formations in upland areas north and south of the Livermore Valley.

2) Evidence for offset of near surface materials beneath Livermore Valley has been sought but not found.

3) Movement at Old Ranch Road, southern Contra Costa County, is evident. The movement is more consistant with differential subsidence of valley alluvium relative to indurated materials in the Dougherty Hills than with fault creep.

4) Recent fine grained alluvial deposits appear to have accumulated to a greater thickness east of the fault suggesting that recent movements along the fault may have influenced drainage and deposition.

On the basis of the above, it appears that the Pleasanton Fault was an active tectonic feature in Meistocene and possibly early recent times but that present tectonic movements if any are being absorbed essentially plastically by alluvium within Livermore Valley. Therefore, the prospect for surface rupture along the Pleasanton Fault appears low within Livermore Valley. Passive or minor tectonic movements along the fault trace are possible in older more brittle materials exposed in the hills north and south of the valley. These could result in damage to structures built over the fault trace but the risk to life safety appears slight.

b) Mission Fault: A Special Studies Zone associated with the Mission Fault has been created by the State of California (Slosson, 1974b) and Woodward-Lundgren and Associates (1973) attributed miscroseismicity to this fault system. However, recent studies (Union City and Fremont Seismic and Safety Element Reports, 1975) have failed to confirm the Mission Fault as a recent geologic feature, and its potential for significant activity appears slight.

c) Other Fault Systems: The seismic potential of fault systems in eastern Alameda County has recently been evaluated (Wight, 1974, Blumeand Associates, 1972) in connection with U.S.A.E.C. mandated studies of the Lawrence-Livermore Radiation Laboratory. Criteria used during this evaluation are those set forth by the U.S.A.E.C. in 10 CFR, Part 100, Appendix A and are more restrictive than those adopted by the California Mining and Geology Board pursuant to the Alquist-Priolo Act. However, faults classed as active under criterion one of 10 CFR, Part 100, Appendix A - movement at or near the ground surface at least once in the last 35,000 years - would also be considered as active under State guidelines unless a very detailed investigation including age dating had been completed.

Faults classified as active under U.S.A.E.C. criterion are listed in Table 2-2 with evidence for recent activity briefly summarized.

In addition to the faults described in Table 2-2, five other faults in eastern Alameda County are classed as active under additional highly restrictive U.S.A.E.C. criteria. These are the Mocho Fault, Corral Hollow Fault, Dougherty Fault, Carnegie Fault and Patterson Pass Fault. However, data presented concerning these faults (Wight 1974, Blume and Assoc., 1972) does not provide any evidence of recent movement on these structures. Therefore, they should not be considered active under California Mining and Geology Board criteria unless further investigations reveal evidence of recent activity.

Primary and Secondary Seismic Hazards

Primary seismic hazards include those directly related to fault movements, tectonic creep, surface rupture and regional uplift or subsidence. Secondary effects are those related to the response of geologic materials to the passage of earthquake energy through them. These include ground shaking, soil liquefaction, lurch cracking, laterial spreading, differential settlement or compaction, and seismically induced landslides on land and tsunamis and seiches in water bodies.

A) Primary Hazards:

1) Tectonic Creep: Tectonic creep has been documented along the Hayward and Calaveras Fault systems within Alameda County. Creep on the Hayward Fault has resulted in building damage at several locations in the East Bay as a result of structural distortions caused by relative ground movements on opposite sides of active fault traces.

   Creep appears to be concentrated along relatively narrow zones and is frequently episodic in character (Nason and others, 1974). Creep areas along active faults can frequently be identified in advance of construction by such features as offset fence lines and road centerlines or distortions in repreated survey measurements. Damaging effects of creep can be minimized by suitable setbacks from active fault traces as located during detailed geotechnical investigations. Tectonic creep does not present a hazard to life safety.

2) Surface Faulting - Ground Rupture: Ground rupture has been documented along the Hayward Fault as a result of earthquakes in 1836 and 1868 and occurred on the Calaveras Fault in 1861. A good correlation exists

Table 2-2 POTENTIALLY ACTIVE FAULTS IN EASTERN ALAMEDA COUNTY

Fault	Known Length[1] (mi.)	Potential[1] Rupture Length (mi.)	Maximum Credible Earthquake[1]	References for Recent Activity	References
Greenville-Riggs Canyon	26	13	6.7	Horizontal slickenside surfaces, gouge zones and a sag pond. Stratigraphy indicates vertical movements as well as horizontal	Wight, L.H (1974)
Livermore	21	10.5	6.5	Strong groundwater barrier in Livermore Valley. Possible correlation of swarm of Mag 4.0-4.2 earthquakes in 1943. Offset of beds in Livermore Fm, slickensides and gouge visible in exposure in landslide scar on east side of Oak Knoll west of Livermore	Wight, L.H. (1974) Cal. Dpt. of Wat. Resources (1966, 1974)
Ramp Thrust	10.6	5.3	6.2	Displacement of caliche layer developed in Livermore gravel beds and related to present ground surface, exposure immediately south of intersection of East Avenue and Greenville Road, Liv. Prominent slickensided shear plane.	Blume & Assoc. (1972)
Tesla-Stand 2	21	10.5	6.5	Gravimetic anomalities, breaks in seismic refraction profile, probable displacement of soil layers in utility trench south of Lawrence-Livermore Lab, may include overthrust of Livermore gravel onto recent gravel. Displacement of soil layers between seismic lines indicated. Geomorphic evidence suggests recent alteration of course of Arroyo Seco Creek to position along north side of fault trace.	Blume and Assoc. (1972)

[1]From Wight, L.H. (1974)

between a fault scarp in the Dublin area and a recent trace of the Calaveras Fault and this appears to mark the rupture zone along the Calaveras Fault. Studies by Radbruch (1967) have approximately located lines of ground rupture during the 1868 earthquake on the Hayward Fault.

While it is generally asssumed that surface rupture may be expected to be repeated along active fault traces, the historic record in California is too short to provide specific support to this belief. A recent study of surface faulting in Owens Valley, where arid conditions and lack of development permit preservation of surface features provides geologic evidence of repeated recent movements along a single fault trace (Slemmons, 1975).

Studies by Woodward-Clyde and Associates (1970) have provided estimates of amounts of horizontal and vertical deformation that may accompany a major earthquake on the Hayward Fault. Based upon these estimates, they have made recommendations for relatively safe setbacks for various types of structures in an area of proposed development in Fremont. Other consultant have made similar estimates of safety setbacks for various locations along the Hayward and Calaveras Fault systems. Such site specific studies could be extended to other fault systems if found necessary.

Up to three feet of vertical offset occurred as a result of surface faulting during the major earthquake that struck San Fernando Valley in 1971. Surface traces passed through residential areas and resulted in severe damage to and local collapse of wood frame homes but did not result in more damage on a track basis than was experienced near the foot of the San Gabriel Mountains where poor soil conditions led to violent ground shaking (Steinbrugge and others, 1971). It is probably that greater amounts of offset could be experienced during a major earthquake on the Hayward or Calaveras faults and that such offsets could lead to the collapse of rigid concrete or steel commercial or industrial buildings. If so, a threat to life safety would exist but such a threat viewed on a county-wide basis does not appear to be as great as that posed by the collapse hazard arising from violent ground shaking or gound failure.

3) Regional Uplift or Subsidence: Permanent uplift and subsidence was observed over large areas in Alaska following the great earthquake in 1964. Many coastal areas were submerged or brought within the zone of tidal influence while shealing of harbors occurred at other locations. Similar regional movements have not been experienced following major Bay Area earthquakes where offsets are largely lateral.

Seed (1969) has stated that it is prudent to consider the potential for one to two feet of vertical displacement adjacent to the Bay as a result of regional ground movements following major earthquakes. Movements of this magnitude would have neglibible effects upon developments in unincorporated areas of the County. The hazard to life safety posed by movements of this magnitude is slight.

B) Secondary Hazards:

1) Ground Shaking: Ground shaking caused by energy released during a major earthquake is the principal perceived feature of an earthquake and the chief cause of structural damage. The amount of ground shaking varies depending upon earthquake magnitude and site conditions. As reported by Oakeshott (1969), considerable differences were noted in amount of ground shaking in downtown San Francisco during the great earthquake in 1906 and were related to areas underlain by fills versus those on bedrock. Attenuation of ground shaking occurs with distance from an earthquake epicenter. However, little attenuation is observed within about 15 miles of a major fault during a major earthquake (Seed, 1969) and Burkland and Associates (1975) has determined that potentially damaging ground shaking could be experienced as far east as the Livermore Valley during an earthquake of magnitude 7.0 or greater on the San Andreas Fault which is located west of Alameda County. Therefore, all urbanized portions of the County would experience strong ground shaking during a major earthquake on any of the Bay Area faults. Some systematic attenuation of ground motion is possible in lightly settled areas in eastern Alameda County and the potential for damage correspondingly reduced. However, if the Greenville-Riggs Canyon fault is active, strong, locally-generated groundshaking could be experienced in eastern Alameda County as well.

   The threat of structural damage owing to ground shaking is therefore general throughout Alameda County. Collapse of old or poorly constructed buildings is possible particularly in areas underlain by poorly consolidated alluvial deposits such as the western Bay Plain and portions of the Livermore Valley. Corresponding hazards to life exist. Displacements of building contents during severe ground shaking could also present life safety hazards.

2) Soil Liquefaction: If loose or medium dense water-saturated cohesionless soils (such as sands) are subjected to earthquake vibrations, they tend to compact resulting in an increase in pore water pressure and a resulting movement of water from the voids (Seed, 1969). Water is thus caused to flow upward to the ground surface resulting in a "quick" or liquefied condition.

   During such an event heavy structures may sink or rotate while light structures such as fuel tanks or utility lines may rise to the surface. Severe damage may occur in either case.

   Areas potentially subject to liquefaction within Alameda County are those underlain by unconsolidated, sandy subsoils with a relatively high water table. Recent studies by the State of California (1974) indicate a liquefaction potential for alluvial deposits with a water table within 50 feet of the ground surface - most of the Bay Plain, western Livermore Valley and Las Positas Valley - but studies by the U. S. Geological Survey (Youd, 1973) indicate that areas of moderate to high liquefaction potential in the Bay Plain are limited to portions of the Plain where depths to ground water are 10 feet or less.

Based upon the U.S. Geological Survey criteria, unincorporated areas where soil liquefaction may occur include most of San Lorenzo, portions of the Ashland district where a high water table has been observed and small County enclaves west and south of Hayward. Applying these criteria to the Livermore Valley, indicates that soil liquefaction may be experienced in alluvial portions of the Dublin District lying west of the Calaveras Fault and possibly in some areas southwest of Pleasanton where disposal of sewage effluent may have led to the development of shallow, perched water bodies. Other isolated areas where liquefaction may occur probably exist in Alameda County but have not yet been identified owing to lack of geotechnical data.

Loss of life could accompany collapse or severe rotation of buildings rusulting from soil liquefaction. Displacements of contents owing to settlement or rotation of structures could also be hazardous to persons.

3) Lurch Cracking: Lurch cracks occur extensively in surface soils and are most common in areas where subsurface liquefaction has occurred. Lurch cracks generally form random patterns and are observed in areas underlain by weathered rock or alluvial deposits (Oakeshott, 1969).

   Lurch cracking is therefore, most likely to be observed in areas of liquefyable soils outlined above but random cracking following a major earthquake may be observed widely within the County following a major earthquake.

   Lurch cracking will contribute to structural damage and collapse potential if cracks propagate into building foundations but are not of themselves a significant threat to human lives unless their sudden appearance produces panic in a crowd.

4) Lateral Spreading: If liquefaction occurs in or under a sloping soil mass, the entire mass will move laterally toward any unsupported face such as a stream bank or excavated channel. Such movements have been observed in natural materials and fills (Seed, 1969) Within Alameda County, they may occur in areas subject to soil liquefaction and will most probably occur adjacent to stream and flood control channels in western Livermore Valley and along floodways in the Bay Plain.

   Structural damage and building collapses could occur during such movements with corresponding threats to life safety.

5) Differential Settlements: Compaction of poorly consolidated cohesionless soils as a result of earthquake vibrations has been widely observed (Seed, 1969). Either reasonably uniform or differential ground settlements will be observed as a result of this process. Widespread settlements will have effects similar to those resulting from regional tectonic subsidence while differential movements will lead to building damage and tilting.

   Regional compaction settlements are important only if ground level

changes result in inundation of areas previously above Bay or reservoir levels. Few developed areas within unincorporated portions of the County would be affected by compaction settlements of as much as two feet as were experienced during the great Alaskan earthquake of 1964 (Seed, 1969).

Differential settlements would likely be observed in areas subject to soil liquefaction as outlined above. This effect might also occur in other portions of the Bay Plan and Livermore Valley underlain by poorly compacted younger alluvial fan deposits. It would appear that damage and collapse and life safety hazards arising from differenital settlements would be greatest in buildings containing several structural elements e.g. a pier or pile outer foundation with internal columns supported on a slab would be an extreme case.

6) Seismically Induced Landslides: Landslides, rock falls, avalanches and mud and debris flows are common in upland areas during moderate to major earthquakes (Oakeshott, 1969). Areas subject to slope failures unrelated to earthquakes are most likely to experience these secondary seismic effects.

Maps based on photo-interpretation (Nilsen, 1973) show known moderate to large-sized landslides within Alameda County. These and maps of adjacent areas have been analyzed (Wight and Nilsen, 1974) to provide a summary of landslide frequency on a regional basis. These data indicate that within Alameda County areas of relatively high landslide frequency occur in upland areas northeast of Castro Valley and north of I-580, in the Dougherty Hills north of the Livermore Valley and are a general condition in the Diablo Range in Southern Alameda County. Seismically induced slope failures may be most common in these areas during a major earthquake.

Sliding is also anticipated widely along the west side of the San Leandro and Hayward Hills during a major earthquake on the Hayward Fault in response to high ground accelerations that are anticipated in this area. A major earthquake on the Calaveras Fault could trigger widespread movements on the east side of Pleasanton Ridge for the same reason. The Castlewood subdivision appears particularly vulnerable since it is built upon a large old landslide with local areas of renewed sliding on its lower slopes.

Collapse of natural stream banks could occur widely during a major earthquake. Threats to structures would be greatest in areas such as Castro Valley where homes encroach closely on San Lorenzo Creek.

Structural damage or collapse could occur either as a result of loss of support from beneath a building or inundation by debris from above. Numerous potentially endangered structures exist in upland areas of Alameda County and seismicly induced landsliding could be an important contributor to loss of property and life during a major earthquake in the Bay Area.

From the standpoint of landslides blocking highways, serious interference with east-west movements of emergency vehicles following a major earthquake shold be anticipated. Natural and cut slopes along Crow Canyon Road, I-580 and Niles Canyon Road the only east-west traffic corridors providing efficient access between the Bay Plain and the

Livermore Valley are likely to fail extensively in response to earthquake vibrations. Unless the large viaduct on I-580 in Altamont Pass collapsed, it is probable that emergency vehicles from the San Joaquin Valley could reach eastern Alameda County following an earthquake disaster. However, help from the east for the Bay Plain could be prevented for a critical interval owing to landsliding in the East Bay Hills.

As tragically experienced during the Hebgen Lake earthquake in 1959, seismically induced landsliding can result in death even in non-structural situations. As part of safety planning, campgrounds and significant day use areas within regional parks should be evaluated with respect to landslide and rockfall hazards. If major risks are found to exist, facilities should be relocated to safer sites.

7) Tsunami Hazards: A Tsunami or seismic sea wave may be generated by any great earthquake in the Circum-Pacific Area - as the Alaskan Earthquake of 1964. Damage within Alameda County as a result of such an event has not been experienced. However, studies by the U.S. Geological Survey (Ritter and Dupre, 1972) indicates that bayshore portions of Alameda County lying below roughly 5 feet in elevation could be inundated by a tsunami with a recurrence frequency of once in 200 years, a very infrequent event.

   Warning systems in existence greatly reduce the risk of loss of life during a tsunami. Few structures exist in unincorporated portions of the County that could be threatened by a tsunami.

8) Seiches: Seiches or periodic oscillations, "sloshing", may develop in San Francisco Bay or in reservoirs within the County as a result of a major earthquake. Oakeshott (1969) indicates that the threat to bayside facilities and life posed by a seiche in San Francisco Bay is fairly low. Evaluations of the potentials for seiches in various County reservoirs is contained in the section on dam safety.

IV. PLANNING CONSIDERATIONS FOR SEISMIC SAFETY

Land use in unincorporated areas is primarily residential (11, 130 acres). Industrial (3,850 acres) and public and semi-public (4,490 acres) are also significant but it must be realized that the intensity of use of both the industrial and public lands may be quite low. Of chief concern is the location of critical facilities and facilities with high intensity public use in areas with high potential primary and secondary earthquake hazards.

There are two areas of emphasis with broad implications for planning and land use controls. The first deals with the recognition that existing building stock must be assessed for its hazard to public safety. Although large areas of the County remain undeveloped many widespread parts of the community must be assessed. Interpretations then must be made for unincorporated urban and rural areas. The second area of emphasis is in assessing the seismic hazards and risks for developed and undeveloped areas. In addition to including this as a part of the implementation program for the city-county coordination potentially will achieve a uniformity on information on geology and structures and recommending needed changes in ordinances.

Other areas of consideration for planning encompases the public safety considerations relating to dams and reservoirs and associated land uses. This subject is covered in the Safety Element of the General Plan.

Recognizing that planners must continue to develop policies for both existing land use and any project proposed in the future, criteria can be developed for four categories of primary and secondary seismic events:

- surface faulting
- ground shaking
- ground failure
- tsunami and seiches

Surface faulting

Unincorporated areas along potentially active faults must be examined (identification of potentially active faults is currently proceeding). There is general agreement among geologists that additional ruptures will occur along fault traces that have ruptured but especially if past evidence of rupture is apparent. Because of this displacement which can occur along faults considerable damage to public and private structures as well as loss of life can occur.

Corrective measures as well as preventative measures suggested by this problem involve establishing a hazardous building abatement program, establishing setback distances, geologic hazard zoning, and prohibition of use in areas of high hazard. The hazardous building abatement program would primarily be the identification of high intensity use buildings such as schools, hospitals, auditoriums and offices. It could even include apartments or commercial buildings located close to or on identified faults. It is in the public interest to phase out these buildings over time primarily for public safety reasons.

Setback distances would be appropriate for proposed development. In several cases where large scale development has been proposed setback distances of up to 1000 feet have been suggested. Distances will vary depending upon accuracy of fault trace, anticipated fault movement, inclination of fault plane, and potential activity as well as any secondary fault traces identified. Setback distances are a form of geologic hazard zoning which have the advantage of being site specific.

Hazard zoning which could include areas of ground failure (landsliding) and flooding would provide a realistic physical constraint to be added to land use planning. It could be incorporated into zoning ordinance considerations or be a separate and overriding environmental criterion determining the appropriateness of the particular proposed use. If it is part of the zoning ordinance, minimum site and investigative safety standards should be included.

Ground shaking

Most earthquake damage occurs from earthquake caused ground shaking. Areas underlain by thick deposits of saturated sediments can be expected to have a higher intensity of shaking than more consolidated and older formations.

Other factors such as distance to the fault and the characteristics of the earthquake play important roles. Estimating damage or assessing earthquake impact involves identifying the effect of local geology on modifying earthquake motion and determining potential for building damage.

The implications for planning and land use are clearly rleated to the history of the site and structures on the site and how carefully the structure was engineered. Historical data on seismic events will allow empirical correlation of ground shaking effects. Interpretation of this information must be done carefully; similar information may be interpreted by qualified personnel from most good geologic maps.

Knowledge of gound shaking effects may be cause to implement low intensity land use controls especially when interpreted with other seismic and/or general plan considerations. Geologic hazard zoning offers a possibility for identifying hazard prone areas. Ordinance requirements for site and structural investigation by the developer are in effect. Problems associated with prediction of strong motion characteristics must be recognized. Finally, a hazardous building abatement program based upon identification of areas and structures most prone to ground shaking effects is advisable.

All man-made structures are subject to the hazards of damage from the effects of earthquakes. Older buildings which were built prior to the adoption of more stringent design requirements for earthquake resistance could be considered hazardous. Fortunately, a large share of the existing buildings in the unincorporated area of the County were built after the adoption of a County Building Code in 1946. It is also fortuante that most buildings are only one or two stories in height and many are of wood frame construction. Historically, these buildings have had good performance in past earthquakes. Consequently, the problem of hazardous building in the unincorporated area is small as compared to the older cities with a larger number of older and taller buildings. Nevertheless, a program of abatement of hazardous buildings would be desirable. However, experience with abatement of hazardous school buildings as required by the Field Act revealed that, despite the potential to apply full financial resources of the State of California, school districts are still maintaining some pre-1933 hazardous buildings. Therefore, such a program would require massive State or Federal assistance to owners of hazardous buildings and the tennants therein.

<u>Ground failure</u>

Instability is a result of materials tending towards equilibrium. It is commonly recognized as settlement, liquefaction and land slides. Failure is caused by earthquakes, weak materials, erosion and heavy rainfall. Man-caused ground failure is caused by undercutting or oversteepening of slopes, overloading of slopes with fill, extensive irrigation, poor drainage, ground water removal, and vegetation removal. Clearly the implications extend to effects which are induced by seismic events, weather and interference by man.

Assessment of ground failure hazards may be made through mapping and data on areas most subject to landslides and liquefaction, lurching or cracking. Slope maps, landslide maps as well as soils, rainfall and vegetation maps also contribute to the assessment. USGS Basic Data Contribution #63 - Isopleth Map of Landslide Deposits estimates landslide potential for Alameda County at 1 to 125,000 scale and represents one methodology which can be applied.

Appropriate planning and land use controls can be developed through study and mapping on conjunction with geologic and soil interpretation. One on-going program involves soil mapping at USGS 1 to 24,000 scale for this purpose. Other controls such as geologic hazards zone and documentation on static and dynamic conditions are suggested.

Risk

The efficiency of seismic safety programs lies in the definition of acceptable levels of risk for the community. The limits of the local programs in the words of Senator Alfred Alquist "depends on how well we make the general public aware of the dimensions of the seismic risk and the choices available to them." The criteria for determining risk is based upon:

- reduction in loss of life and injuries.
- reduction or prevention of property damage, and
- prevention of economic and social dislocations resulting from future earthquakes.

With these criteria in mind a hierachy of risk may be established. At the unacceptable risk extreme critical structures such as nuclear reactors and dams and other buildings the failure of which would affect substantial populations. At the other extreme would be open space the highest acceptable risk where failure would affect practically no structures or persons.

While the major portions of urbanized unincorporated land are in residential use, some structures such as schools and hospitals and many utilities would be in the unacceptable risk category. For example, Fairmont Hospital is located near the Hayward Fault and a determination of its suitability for continue public use must be made.

LEVEL OF ACCEPTABLE EXPOSURE TO RISK	EXPLANATIONS	KINDS OF LAND USES AND STRUCTURES
1. Lowest level of acceptable exposure to risk	Failure of a simple structure may affect substantial populations. Structures whose continued functioning is critical to the community welfare or whose failure might be catastrophic. These structures should experience no structural/mechanical failure or damage to interior equipment. These structures must be fully operational immediately following a major earthquake.	Critical structures such as nuclear reactors, large dams, plants manufacturing or storing explosives or toxic materials
2. Very low level of acceptable exposure to risk	Failure of a single structure may affect substantial populations. Structures whose use is critically needed after a disaster. These structures must not experience structural/mechanical failure, with little or no damage to interior furnishings and equipment. They must be fully operational following a major earthquake.	Essential structures such as hospital, fire stations, important utility centers, critical transportation elements such as bridges and overpasses, fire, police, and emergency communication facilities
3. Low Level of acceptable exposure to risk	Failure of single structure would affect primarily the occupants. Structures of high occupancy or whose use after a disaster would be particularly convenient though not critical. No structural collapse should occur or damage that cannot be repaired quickly.	High occupancy structures such as schools, churches, civic buildings, theaters, large hotels, jails, dormitories, high-rise apartment or office buildings
4. Ordinary level of acceptable exposure to risk	Failure of a single structure would affect primarily the occupants. No structural collapse should occur; damage may occur to mechanical systems and contents of building.	Relatively low occupancy structures such as most industrial or commercial buildings, small hotels and apartment buildings
5. More than ordinary level of acceptable exposure to risk	Failure of a single structure would affect primarily the occupants. No structural collapse should occur. Damage may occur to mechanical systems and contents of building.	Single family residences, warehouses, parking structures
6. Highest level of acceptable exposure to risk		Open Space only

Source: Meeting the Earthquake Challenge, Final Report to the Legislature, State of California by the Joint Committee on Seismic Safety, January, 1974, California Division of Mines and Geology, Special Publication 45.

Structural hazards

The unincorporated portions of Alameda County include all forms of land use found in cities although a major portion of unincorporated lands are in open space and agricultural uses, there are five areas in the county (Ashland, Cherryland, San Lorenzo, Castro Valley, Dublin) which are largely developed. Outside of these five areas where structures exist the density is low to suburban.

Structural hazards then exist in at least two ways:

- threats to existing structures.
- threats to proposed structures.

The application of the Uniform Building Code in the County has improved the more recent housing stock especially since seismic design standards were incorporated. Existing housing and other buildings were not surveyed due to limitations in time and money (see Implementation program). Mitigation of threats to proposed developments is expected to occur through building code enforcement in the short term and through revisions in zoning and subdivision ordinances, land use planning and specific plans for areas of critical environmental concern in the long term.

An initial step in the hazard identification program is the base data mapping which is currently being completed. In conjunction with data compilation (maps and written reports) for the Seismic Element and hazards, coordination with the 13 cities is currently being made. A consistent method of mapping and report writing is needed among the various jurisdictions.

Phase I of the hazards mapping and determination is to identify and map the primary and secondary earthquake effects. Information on ground shaking, rupture and ground failure through settlement, liquefaction and land sliding are being compiled and mapped by the County Geologist.

Determination of hazard in relationship to land use constitutes the Phase II program. It has been documented that hazard to life and property is a complex nexus of physical interaction between local geology and the supervening structures. Secondary effects of earthquake, for example, are related to both soils, slope and ground water level, as well as the local geology. Earthquake response of structures is dependent upon the frequency and amplitude of the shock and the seismic adequacy of the structure. (As shown on Modified Mercali scale.)

V. GOALS AND OBJECTIVES

Goals: Countywide and Unincorporated Area

1. To the greatest possible extent, protect citizens, land and structures within Alameda County from the hazardous results of seismic activity.

2. To coordinate seismic protection activities with all state, regional and local agencies.

3. To educate and inform the public at large and land developers on seismic activity and protective measures.

Objectives: Countywide

1. Prepare, adopt and implement seismic policies, plans and legislation on a countywide basis to reduce the hazards of seismic activity.

2. Establish a Countywide information collection, storage and retrieval system for seismic activity to reduce duplication of efforts at the regional, County and local level.

3. Coordination with cities within the County to develop rational land use and emergency service plans.

4. Develop a seismic educational program for use by schools, developers and the public at large.

Objectives: Unincorporated Area

1. Provide an acceptable level of safety from seismic hazards by continuing to assess and evaluate local geology and structures and take action to abate public safety hazards.

2. Develop a rational land use plan based upon knowledge of local geologic conditions and potential seismic events. This would involve the development of seismic constraint maps which would then be applied to land use plans.

VI. IMPLEMENTATION RECOMMENDATIONS

Adequacy of Existing Regulations

Pursuant to provisions of the Alquist-Priolo Act, State of California and related County ordinances, applicants to the Planning Commission, Zoning Administrator or Building Official are required to present evidence of site suitability before their application can be approved. Within Special Studies Zones, applications for other than one or two story single family homes of wood frame contruction are required to be supported by geologic data demonstrating that the property is not traversed by a potentially active fault or that an adequate setback can be maintained. Under the County Building Code, the Building Official may require this finding as well for single family residences if a preliminary evaluation of the building site by the County Engineering Geologist, a member of his staff, indicates that a potentially active fault may traverse the site. This requirement would also be applied to proposed construction in affected portions of Eastern Alameda County if future investigations demonstrate that active faults exist.

Section 2905, Chapter 29, Alameda County Building Code, was amended effective August 1, 1974 to require applicants for new construction to submit soils and/or geologic reports for sites affected by a number of geologic and soils conditions including the presence of primary and secondary seismic hazards. Section 2905 is reproduced for reference

Section 2905 and a related Section 2903 governing grading and engineered fills have been found to work well in practice and no need for revisions are currently apparent. Intelligent administrative enforcement of these ordinances by technically qualified personnel is essential to assure that the public is reasonably protected from seismic and other geologic hazards. While additional geologic knowledge and changes in engineering practices may make future revisions of these ordinances necessary, such revisions must be done in an orderly manner so as not to disrupt construction needed to meet human needs or to introduce factors where added costs exceed added benefits.

In December 1973, Woodward-Lundgren and Associates, Inc., provided the Alameda County Public Works Agency with Preliminary Geologic Hazards Maps coverning most of the County at a scale of 1 inch equals 2000 feet. These maps are also used by the County Planning Department. These maps when combined with some other geotechnical data such as soil maps prepared by the U.S. Department of Agriculture, Soil Conservation Service, and a reconnaissance of the property are generally adequate to determine the need for a detailed, site specific soil and/or geologic report. Such detailed reports are prepared by private engineering and geologic consulting firms and reviewed for technical adequacy by the Building Official and the County Engineering Geologist.

Experience has shown that revisions of these preliminary maps are desirable in some areas based upon new data and that some additional compilations will be of great value in general and Public Works, Planning and Building Code enforcement. Therefore funds have been included in the Public Works Agency fiscal year 1976 budget to permit revision and upgrading of a portion of the map set under the supervision of the County Engineering Geologist. It is intended to begin with the Hayward and Dublin quadrangles where development

is presently most active and proceed in the future to other areas of the County as time and funds permit.

Section 2905, Chapter 29
Alameda County Building Code
(effective August 1, 1974)

Section 2905, Chapter 29, Part VII: Foundation investigation. Section 2905 on pages 446 and 447 is amended to read:

Section 2905 Soils and Geologic Investigation.

(a) **When required.** A soil and geologic investigation shall be required in the following circumstances.

1. When the allowable soil pressure used in the design of the foundation exceeds 2,000 psf.
2. When the building is proposed to be supported in fill.
3. When the slope of the natural ground within 30 feet of any building or structure exceeds 25 percent.
4. When a cut or a fill exceeding 5 feet in depth at any point either exists or is proposed and the slope of the natural ground within 30 feet of the building or the cut or fill exceeds 10 percent.
5. When expansive soils are present.
6. In any subdivision as defined in Section 11535 and 11535.1 of the Business and Professions Code of the State of California which has been recorded after September 17, 1965. Where critically expansive soils or other soil conditions are present within a subdivision, which if not corrected would lead to structural defects, a soil and geologic investigation report shall be required for each lot in the subdivision.
7. On a building site traversed or suspected to be traversed by a fault.
8. In areas of known or suspected geological hazards, including landslide hazards and hazards from earthquake caused ground shaking.
9. When otherwise required by the Building Official due to proposed design of the structure or due to topographical or geological conditions on the building site.

EXCEPTION: A soil investigation shall not be required for additions to existing dwellings or for J Occupancies.

(b) **Investigation.** Those portions of the investigation that are civil engineering as defined by Section 6734 of the Business and Professions Code of the State of California shall be prepared by a soils engineer who is a civil engineer registered by the State of California. Those portions of the investigation that involve the practice of geology as defined by Section 7802 of the Business and Professions Code of the State of California shall be prepared by an engineering geologist registered and certified by the State of California.

The investigation shall be based on observation and tests of the materials disclosed by boring or excavation made in appropriate locations. Additional studies may be necessary to evaluate soil strength, the effect of moisture variation on soil, bearing capacity, compressibility and expansiveness.

(c) **Reports.** The soil and geologic investigation report shall contain all of the following as they may be applicable to the particular site and any recommendations contained therein shall be subject to the approval of the Building Official.

1. A description, location, and a reference elevation of all borings or excavations measured to the nearest one foot.
2. A classification of the soil.
3. Pertinent laboratory test data.
4. If the soil is classified as expansive, the report shall include special recommendations as to the design of foundations and concrete slabs supported on the ground in order to eliminate detrimental effects on the foundation or slabs.
5. A description of ground water conditions if they exist.
6. A recommendation as to method for excavating and compacting soils.
7. A recommendation regarding drainage and erosion control.
8. A recommendation as to setback for buildings or structures from top or toe of slopes.
9. A recommendation as to the allowable soil pressure to be used in design of any proposed building or structure.
10. A recommendation as to the lateral soil pressure to be used in the design of retaining or basement walls if any such walls are proposed.
11. A recommendation as to the design of foundations if such foundations are proposed to be located partly on natural soil and partly on fill soil.
12. An evaluation of the expected settlement of any fill and any proposed building or structure.
13. An evaluation of the stability of any natural slope and any proposed or existing cut and fill slope.
14. An index map showing the regional setting of the site.
15. A description and map of the geology of the site and the geology of adjacent areas if the adjacent geological features affect the site.
16. A description of the geological investigative techniques employed.
17. If geological hazards exist, the report shall include recommendations to mitigate these hazards.
18. A professional engineering and geologic opinion as to the safety of the site from the hazards of land slippage, erosion, settlement or seismic activity.

The site development and all buildings and structures shall be designed and constructed in accordance with the recommendations contained in the soil and geologic investigation reports.

(d) **Final Report.** Upon completion of rough grading work and prior to the approval of the foundation for any proposed building or structure, the following shall be provided.

1. An as-built grading plan prepared by a registered Civil Engineer including original ground surface elevations, as-graded ground surface elevations, lot drainage, and location of all surface and subsurface drainage facilities.
2. A complete record including location and elevation of all field density tests, and a summary of all field and laboratory tests.
3. A declaration by the Civil Engineer and Geologist in the form required by the Building Official that all work was done in accordance with the recommendations contained in the soil and geologic investigation reports as approved by the Building Official and the approved plans and specifications.

Where soil or geologic conditions encountered in grading operations are different from that anticipated in the soil and geologic investigation reports or where such conditions warrant changes to the recommendations contained in the original soil investigation, a revised soil or geologic report shall be submitted for approval and shall be accompanied by an engineering and geologic opinion as required in Section 2905(d), Item 14.

Adequacy of Existing Regulations - Unincorporated Area

Zoning Ordinance

With the exception of the Alquiest-Priolo Act the present Ordinance does not contain any earthquake regulations. The Alquist-Priolo Act designates special studies zones (fault zones) within which structures for human occupancy must be subjected to evaluation by a qualified engineering geologist. Results of studies based on extensive geologic investigation should be used to revise the Zoning Ordinance.

Grading Ordinance

A Grading Ordinance does not exist for Alameda County. Grading is handled through Building Inspection and the Building Code and the Subdivision Ordinance. A Grading Ordinance is being prepared for adoption in Fiscal Year 1975-1976.

Subdivision Ordinance

The existing County Subdivision Ordinance contains the necessary provision for requiring a soils report prepared by a soils and foundation engineer, a geologic report prepared by an engineering geologist, an erosion control report, and a grading plan prepared by a licensed civil engineer. Soils and geological reports will be used as part of the Countywide data system.

Building Code

The Building Official requires a soils, engineering and geology report if he deems it necessary. Abatement of unsafe buildings is accomplished through Title 7, Chapter 7, Alameda County Ordinance Code. (See page 2-31 and/or Section 2905, Chapter 29, Alameda County Building Code.

General Plan Policies

No specific policies relating to seismic safety are included. Policies relating to general public safety and appropriateness of land use are contained in the General Plan. Adoption of the Seismic Safety and Safety Elements of the General Plan will provide seismic policies. The adopted Open Space Element and Conservation Element also protect areas vulnerable to seismic activity.

Implementation-Geotechnical Studies

A program for preparation and upgrading of geologic and seismic hazards maps exists within the Alameda County Public Works Agency. Work in progress is under the supervision of the County Engineering Geologist. Some items in the contemplated program may require the sources of specialized geotechnical consultants such as a more detailed evaluation of soil liquefaction potential.

As a first item in this program, miscellaneous geotechnical data available in the files of several county departments are being assembled in a general file. This file will be more readily available to County personnel and will be open to members of the public in accordance with established open file procedures.

The data file will chiefly include reports bearing on unincorporated areas but will also include reports on County facilities located within cities. Copies of reports on city areas brought to the attention of County personnel, e.g. as a result of Alquist-Priolo Act reviews, will be included with the approval of the cities affected.

In order to assure that an adequate future program of geologic and seismic hazard evaluation is maintained, the following program is recommended for implementation.

1) Implementation of the program of upgrading of geologic hazard information authorized in the Public Works Agency should be assigned a specific priority in the work load of the County Engineering Geologist.

2) A study to more accurately evaluate the risk of soil liquefaction and related secondary seismic hazards in developing areas should be completed by a qualified soils engineering consultant. Risk maps for Planning and Building Code enforcement should be prepared for portions of the Bay Plain and Livermore Valley under County jurisdiction.

3) Evidence should be developed to determine whether potentially active faults exist in eastern Alameda County. These studies should include field mapping by the County Engineering Geologist followed by programs of geophysical surveying and limited trenching to permit direct inspection if warranted.

4) A system of cross referencing of geotechnical data pertaining to Alameda County should be established. In addition to the file being created within the County, files of soil reports are known to exist in Oakland and Hayward and may have been established by other cities as well. A procedure should be established for cities not maintaining their own files of soils and geologic reports to transmit these to the County Engineering Geologist for inclusion in the County general file.

   Reference lists and maps showing areas covered by these reports should be exchanged between city personnel maintaining the files and the County

Engineering Geologist. Also, it would be beneficial in the future for cities to forward an additional copy of reports documenting active fault locations or identifying areas of secondary geologic hazards to the County Engineering Geologist for his information and use.

Implementation-Planning Programs

A. General Plan and Plan Elements

1) Revision where necessary to achieve conformance with Seismic Safety Element Policies.

2) Incorporation on an ongoing basis of data on geologic hazards and limitations which affect land use and development.

B. Maintain Centralized Data Files and Data on a Countywide Basis in Coordination with Cities

Implementation:
- Resource/hazard mapping program
- City/County Coordination
- Geologic Data Center
- Computer Mapping

C. Coordination with Community Development Planning

Implementation:
- Identification of areas where greatest seismic and structural hazards exist.
- Develop specific community development plans to reflect lower use or changes in development pattern.

D. Building Inspection Programs

Implementation:
- Identification of unsafe structures with high intensity and/or public use in conjunction with field mapping program.

- Determination of corrective measures for identified structures.

E. Citizen Education and Participation

Implementation:
- Educational forums and workshops

GLOSSARY[1]

Active faults. Active faults are faults which show evidence of any or all of the following:
1. Topographic or physiographic expressions suggestive of geologically young fault movements.
2. Fault creep.
3. Records of surface rupture within or adjacent to the study area in historic time.

Aggregate. Materials such as sand, gravel, and crushed rock, with which cement or bituminous material is mixed to make concrete or asphalt.

Alluvial fans. Alluvial fans are built by rivers flowing from mountains onto lowlands. They are low cone-shaped heaps, steepest near the mouth of the valley, and sloping gently outward with ever decreasing slope.

Alluvium. A general term for the sediments laid down in river beds, flood plains, lakes, fans at the foot of the mountain slopes, and estuaries during relatively recent geologic times.

Amplification. The increase in earthquake ground motion that may occur to the principal components of seismic waves as they enter and pass through different earth materials.

Amplitude. One-half the elevation of the crest of a wave or ripple above the adjacent troughs.

Anomaly. A deviation or inconsistency of a specific land feature from uniformity with the larger area.

Anomalous features. See "anomaly".

Anticline. An upfold or arch of rock strata formed by internal earth pressure forming a shape like the roof of a house. Erosion could alter this shape leaving only the inclined strata.

Attitude (of rock structures). A term including the terms dip and strike. The attitude of the flat surface of a sedimentary bed, whether inclined or not, is referred to the horizontal plane. Dip is its slope inclination (in degrees) from this plane, and is measured with a clinometer. Strike is the compass bearing on the line of intersection of its surface with horizontal plane. The terms may also apply to faults, veins, and dikes.

Basalt. A dark-colored, fine-grained volcanic rock, composed essentially of the mineral plagioclase feldspar and one or more dark minerals such as pyroxene.

Bed. The smallest division of a stratified series, and marked by a more or less well-defined plane from its neighbors above and below.

Bedding plane. In sedimentary or stratified rocks, the division planes which separate the individual layers, beds or strata.

Bedrock. Any solid rock underlying soil, sand, clay, etc.

Berkeley hills. The hills on the immediate east side of San Francisco Bay contained within such cities as Oakland, Berkeley, El Cerrito and Richmond.

Bore hole. A hole drilled into the earth for exploratory purposes.

Breccia. A rock composed of angular coarse fragments, commonly cemented together.

Chert. A compact sedimentary rock containing abundant quartz of organic or precipitated origin.

Clastic rock or Clast. A rock which is composed principally of detritus transported mechanically into its place of deposition.

Cohesion, rock. The capacity of a rock to stick or adhere together. In effect the cohesion of soil or rock is that part of its shear strength which does not depend upon interparticle friction.

Cohesive materials. See "cohesion, rock".

Colluvium. Soil deposited by soil creep, landslides and surface wash.

Compaction. Decrease in volume of sediments, as a result of compression of sediments deposited above them.

Competent beds. Those beds or strata which, because of massiveness or inherent strength, are able to lift not only their own weight but also overlying rock. Therefore, such rock material is especially able to withstand failure such as landsliding.

Conglomerate. A rock composed of larger fragments (such as pebbles or cobbles) set in a matrix of finer material (such as sand, silt, and/or clay).

Consolidated material. Soft or hard rock which requires some medium of loosening at the excavation site before it can be handled. The more loosening required (i.e., blasting as opposed to bulldozing) the more consolidated the material.

Continental rock. A rock unit laid down on land as opposed to one laid down in marine water.

Contra Costa Group. The type of poorly consolidated young sedimentary rock found in the Tri-Cities Area east & north of the Berkeley hills ridgeline.

Creep, fault. See "fault creep".

Cross bedding. The arrangement of narrow layers of sedimentary rock such that layers are at angles to rather than parallel to the other layers.

Damping. A resistance to vibration that causes a progressive reduction of motion with time or distance.

Deformation of rocks. A change in the original form or volume of rock masses produced by faulting, folding or other tectonic forces.

[1] Source: The Seismic Safety Study, a joint planning study of the cities of El Cerrito, Richmond and San Pablo, 1973.

GLOSSARY[1]

Detritus. The materials that result from the breaking up, disintegration and wearing away of minerals and rocks resulting in alluvial deposits.

Diatomite. A light friable, siliceous material chiefly produced from the remains of minute forms of algae.

Differential Settlement. Loss of strength or the loss of water and sand through liquefaction often does not occur evenly over broad areas. Thus the ground settles different amounts in adjacent spots. Can be very destructive to buildings.

Dip. See "attitude".

Dip slip. Fault displacement parallel to the dip of the fault. See "attitude" and "slip".

Displacement. The dislocation of one side of a fault relative to the other side resulting from fault movement.

Earth-flow. A slow flow of earth lubricated with water. Earth-flows may be discriminated from earth-slumps by reason of their greater mobility.

Earthquake. Perceptible trembling to violent shaking of the ground, produced by sudden displacement of rocks below and at the earth's surface.

Earthquake focus. See "focus".

Earth-slump. See "earth-flow".

Elastic limit. The maximum stress that a material can withstand without undergoing permanent deformation either by solid flow or by rupture.

Elasticity. The property or quality of being elastic, that is, an elastic body returns to its original form or condition after a displacing force is removed.

Eocene. An epoch of the lower Tertiary period. It ranges from 37 to 38 million to 53 to 54 million years before the present.

Epicenter. The geographical location of the point on the surface of the earth that is vertically above the earthquake focus.

Fan, alluvial. See "alluvial fan".

Fault. An earth fracture or zone of fracture along which the rocks on one side have been displaced in relation to those of the other.

Fault block. A body of rock bounded by one or more faults.

Fault creep. Very slow periodic or episodic movement along a fault trace unaccompanied by quakes.

Fault-scarp. The cliff formed by a fault. Most fault scarps have been modified by erosion since faulting.

Fault set. Two or more parallel faults within an area.

Fault slip or slippage. The relative displacement of formerly adjacent points on opposite sides of a fault. Also known as fault creep.

Fault system. Two or more fault sets formed at the same time.

Fault surface. The surface along which dislocation has taken place.

Fault trace. The intersection of a fault and the earth's surface as revealed by dislocation of fences, roads, by ridges and furrows in the ground, etc.

Fault zone. A fault instead of being a single clean fracture, may be a zone hundreds or thousands of feet wide; the fault zone consists of numerous interlacing small faults or a confused zone of gouge, breccia or other material.

Fault, active. See "active fault".

Fault, inactive. See "inactive fault".

Fault, normal. See "normal fault".

Fault, reverse. See "reverse fault".

Fault, right-lateral. See "right-lateral fault".

Fault, thrust. See "thrust fault".

Faulting. The movement which produces relative displacement of adjacent rock masses along a fracture.

Fissure. An extensive crack, break, or fracture in the rocks.

Flexuring. Synonymous with folding.

Focal depth. Depth of an earthquake focus below the ground surface.

Focus. The point within the earth which marks the origin of the elastic waves of an earthquake.

Fold. A bend in rock strata.

Formation. A rock body or an assemblage of rocks which have some character in common; applied to a particular sequence of rocks formed during one epoch; a rock unit used in mapping.

Fracture. Breaks in rocks due to intense faulting or folding.

Free face. A sloping surface exposed to air or water such that there is little or no resistance to lateral movement of earth materials.

Frequency. The number of seismic wave peaks which pass through a point in the ground in a unit of time. Usually measured in cycles per second.

Friable. A term applied to rocks that are easily crumbled or pulverized.

Geodetic measurements. Controls on location (vertical & horizontal) of positions on the earth's surface of a high order of accuracy, usually extended over large areas for surveying and mapping operations.

Geology. The science which treats of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing.

Geophysical surveys. The use of one or more physical techniques to explore earth properties and processes.

Gouge material. Finely ground material occurring between the walls of a fault, the result of grinding movements.

[1] Source: The Seismic Safety Study, a joint planning study of the cities of El Cerrito, Richmond and San Pablo, 1973.

GLOSSARY[1]

Graywacke. A hard, dark-colored, sandstone composed primarily of highly angular quartz and feldspar in a clay matrix. Usually contains significant quantities of rock fragments.

Ground cracking. Cracks usually occurring in stiff surface materials resulting from differential ground movement.

Ground failure. A situation in which the ground does not hold together such as in landsliding, mud flows, liquefaction and the like.

Ground lurching. Undulating waves in soft saturated ground that may or may not remain after the earthquake.

Ground strength. The limiting stress that ground can withstand without failing by rupture or continuous flow.

Ground response. The reaction of the ground to earthquake shaking.

Group. A local subdivision of a series of rocks, based on lithologic features. It usually contains two or more formations.

Hayward fault. A large and active branch of the San Andreas Fault System. It has been the center of many earthquakes, including the 1868 earthquake which was one of the largest ever to hit Northern California.

Hummocky. Lumpy land, or in small uneven knolls. This condition is a sign of previous extensive landsliding.

Hypocenter That point within the earth which is the center of an earthquake and the origin of its elastic waves.

Inactive faults. Identifiable faults which do not meet any of the criteria listed under "active faults".

Incompetent beds. Opposite of competent beds.

Inelastic deformation. Permanent deformation of materials either by flow, creep, or rupture.

Intensity. (See Table 1) A nonlinear measure of earthquake size at a particular place as determined by its effect on persons, structures, and earth materials. The principal scale used in the United States today is the Modified Mercalli, 1956 version. Intensity is a measure of effects as contrasted with magnitude which is a measure of energy. They are not the same.

Interstitial water. Water contained within the minute pores or spaces between the small grains or other units of rock.

Intrusion. An igneous rock that has been injected into older rocks; it has cooled and solidified from a molten condition under the cover of the surrounding rock mass.

Inundation. Flooding caused by water topping a dam or water released by dam, reservoir, levy or other break.

Isoseismic line. An imaginary line connecting all points on the surface of the earth where an earthquake shock is of the same intensity.

Lacustrine. Formed in a lake.

Landsliding. The perceptible downward sliding or falling of a relatively dry mass of earth, rock, or mixture of the two. Often loosely used to also include sliding of wet earth masses such as mudslides and earthflows.

Left-lateral fault movement. Generally horizontal movement in which the block across the fault from an observer has moved to the left.

Lenticular. Shaped approximately like a double convex lens. When a mass of rock thins out from the center to a thin edge all around, it is said to be lenticular in form.

Liquefaction. A process by which a water saturated sand lens loses coherence when shaken. Involved is the collapse of sand grains into intergranular voids which induces an increase in pore pressure and loss of strength. This loss of strength leads to a quicksand condition in which objects can either sink or float depending on their density.

Lithology. The description of rock composition and texture from observation of hand specimens or outcrops.

Mafic pyroclastic rocks. Pyroclastic rocks containing a high proportion of dark colored (mafic) rock and mineral constituents such as basalt.

Magnitude. The rating of a given earthquake is defined as the logarithm of the maximum amplitude on a seismogram written by an instrument of specified standard type at a distance of 62 miles from the epicenter. It is a measure of the energy released in an earthquake. The zero of the scale is fixed arbitrarily to fit the smallest recorded earthquakes. The scale is open ended but the largest known earthquake magnitudes are near 8-3/4. Because the scale is logarithmic, every upward step of one magnitude unit means a 32 fold increase in energey release. Thus, a magnitude 7 earthquake releases 32 times as much energy as a magnitude 6 earthquake. Magnitude is not the same as intensity.

Melange. A mixture or complex of rocks.

Micro-earthquake. A very small earthquake having a magnitude of 2 or less on the Richter scale.

Microseismic Event. An earthquake or man-induced vibrations observable only with instruments.

Miocene. An epoch of the upper Tertiary period. It ranges from 12 million to 26 million years before the present.

Modified Mercalli. See "intensity".

Monitoring fault movement. Use of survey methods over a period of time to measure displacement caused by creep over a period of time.

Morphology, slope. See "slope morphology."

Mudflow or mudslide. A flowage of heterogeneous debris lubricated with a large amount of water.

Normal fault. Vertical movement along a sloping fault surface in which the block above the fault has moved downward relative to the block below.

Period, natural. See "natural period".

Period, predominant. See "predominant period".

Physiography. A description of existing nature as displayed in the surface arrangement of the globe, its features, atmospheric and oceanic currents, climate, etc.

Plastic deformation. Under some conditions solids may bend instead of shearing or breaking as a result of seismic and geologic forces.

Pliocene. The latest epoch in the Tertiary period. It ranges from 7 to 10 million to 2 to 3 million years before the present.

[1] Source: The Seismic Safety Study, a joint planning study of the cities of El Cerrito, Richmond and San Pablo, 1973.

GLOSSARY[1]

Ponding. Accumulation of alluvial and colluvial deposits behind a fault-produced barrier.

Precipitate. The material resulting from the process of separating mineral constituents from a solution by evaporation (salt, etc.) or from magma to form igneous rocks.

Predominant period. A number representing the time between seismic wave peaks to which a building on the ground is most vulnerable. Usually measured in seconds.

Pumice. An excessively cellular, glassy lava of whitish or gray color. It is very light and will float on water.

Pyroclastic. A general term for fragmental deposits of volcanic materials, including volcanic conglomerate, agglomerate, tuff and ash.

Remote sensing The acquisition of information or measurement of some property of an object by a recording device that is not in physical or intimate contact with the object under study. The technique employs such devices as the camera, lasers, infrared and ultraviolet detectors, microwave and radio frequency receivers, radar systems, etc.

Residual soil. A soil deposit formed by the decay of rock in place.

Reverse or thrust fault. Vertical or nearly horizontal movement along a sloping fault surface in which the block above has moved upward or over the block below the fault.

Right-lateral fault movement. Generally horizontal movement in which the block across the fault from an observer has moved to the right.

Sag ponds. Ponds occupying depressions along active faults. The depressions are due to uneven settling of the ground.

Sand boils. Turgid upward flow of water and some sand to the ground surface resulting from increased ground water pressures when saturated cohesionless materials are compacted by earthquake ground vibrations.

Scarp. An escarpment, cliff, or steep slope of some extent along the margin of a plateau, terrace, bench, and at the top of a slide.

Sediment. Solid material settled from suspension in a liquid.

Sedimentary rocks. Rocks, commonly stratified, formed by the accumulation of sedimentation in water or from air.

Seismograph. An instrument that writes a permanent continuous record of earth vibrations.

Seismic. Pertaining to an earthquake or earth vibration, including those that are artificially induced.

Seismology. The science of earthquakes and related phenomena.

Seismometer. A device which detects vibrations of the earth, and whose physical constants are known sufficiently for calibration to permit calculation of actual ground motion from the seismograph.

Shear. A mode of failure whereby two adjacent parts of a solid, slide past one another parallel to the plane of contact. To subject a body to shear, similar to the displacement of the cards in a pack relative to one another.

Slip, fault. See "fault slip".

Solid flow. Flow of a solid under long-time stress.

Strata. Layers of sedimentary rocks.

Strength, ground. See "ground strength".

Strike. See "attitude".

Strike-slip Fault displacement parallel to the strike of the fault. See "attitude" and "slip".

Strong motion. Ground motion produced by a "strong" earthquake or one capable of producing damage to structures. The magnitude of such an earthquake may vary considerably according to the character of the earthquake.

Structural feature. Features produced in the rock by movements after deposition, and commonly after consolidation, of the rock.

Subsidence. A shrinking of a large area of land, usually observed as a shrinkage.

Surface wash. A loose surface deposit of sand, gravel, boulders, etc.

Syncline. A trough-shaped fold in rocks in which the strata dip inward from both sides toward the axis. The opposite of anticline.

Tectonic. Pertaining to or designating the rock structure and external forms resulting from the deformation of the earth's crust. Pressures causing such deformations often result in earthquakes.

Trace, fault. See "fault trace".

Thrust fault. See "reverse fault".

Topography. The physical features of the land, especially its relief and contour.

Torsional forces. Forces which act to twist the object in question.

Tsunami. A sea wave produced by large areal displacements of the ocean bottom, often the result of earthquakes or volcanic activity. Also known as seismic sea waves.

Unconformity. In sedimentary rocks sometimes strata of intermediate age between younger and older rocks are absent. This is usually caused by total erosion of the middle-aged sediment before the younger sediment was deposited.

Unconsolidated material. Opposite of "consolidated material".

Undulating waves. Waves that rise and fall.

Water Table. The upper surface of a zone of water saturation within the ground.

Wash, surface. See "surface wash".

Wave height. The difference in elevation between adjoining wave crests and troughs.

[1] Source: The Seismic Safety Study, a joint planning study of the cities of El Cerrito, Richmond and San Pablo, 1973.

*Reference in portion of Element written by Planning Department

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